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土壤特性對稻米品質之影響
(三)土壤理化性質對米飯品質之影響

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摘要：本試驗目的在探討土壤各種理化性質對米飯品質的影響，據以作為良質米栽培管理的參考。於1989-1991年調查本省中部地區90處稻田土壤物理化學性質及米飯品質。土壤化學性質調查項目有土壤pH、游離鐵、易還原錳、氧化還原電位。土壤物理性質則調查滲漏速率、穿刺阻力及灰斑層深度。同時也調查土壤各種元素的比值及水稻根活性。米飯品質測定項目為食味品評及米飯物理性質。結果顯示pH較低、易還原錳含量較低及氧化還原電位下降速率較慢之土壤，米飯食味總評及均衡度有較佳之趨勢。生產之稻米食味及均衡度較佳的土壤，其曬田後穿刺阻力有較大的趨勢。曬田常在最適分蘗後行之，曬田程度高者，土壤通氣獲得改善，米質可能因而獲得改進，但使得土壤穿刺阻力亦隨之昇高。土壤剖面灰斑層深度、水田滲漏速率及稻根活性在米質優劣區對比下均無明顯之差異。土壤Ca/Mg比值較高及Mg/K比值較低者，米質食味總評及均衡度亦有較佳之趨勢。

關鍵詞：土壤物理性質、土壤化學性質、氧化還原電位、穿刺阻力、土壤元素比值、米飯食味品質、米飯均衡度、土壤管理模式。

Effect of soil characteristics on rice quality. III. Eating quality of rice as affected by soil physical and chemical characteristics.

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Abstract. This experiment aimed to investigate the effects of soil physical and chemical characteristics on rice qualities. Totally 90 field experiments were conducted at central Taiwan from 1989 to 1991. Soil properties including soil pH, free iron, reducible manganese, redox potential, percolation rate, penetration resistance, depth to gray layer, and ratios among soil nutrient elements were surveyed. Eating quality and balance of cooked rice were also tested by panel evaluation and texturometer, respectively. Experimental results showed

that paddy soils with a lower pH, reducible manganese, and slower declined rate of redox potential, produced higher quality rice with good eating quality and balance. Soils produced rice with better eating quality and balance showed a higher penetration resistance after soil-drying, which is always practiced after optimum tiller number reached, and accompanied by improvement of soil aeration and increase of soil penetration resistance. Thus a higher penetration resistance implied a higher degree of soil-drying and thus a better soil aeration which resulted in production of high quality rice. Soil with a higher Ca/Mg, and lower Mg/K also tended to produce good quality rice. On the other hand, there are no significant differences of depth to gray layer, percolation rates, and root activity of rice, between producing good and poor quality of rice.

Keywords: Soil physical properties, Soil chemical properties, Redox potential, Penetration resistance, Ratios of soil nutrient elements, Rice eating quality, Balance of cooked rice, Models for soil management.

前　言

隨著臺灣經濟繁榮，國民所得激增，帶動飲食習慣的改變，高品質稻米的生產消費已是必行之趨勢，也是目前水稻試驗研究的重要方向。影響稻米品質的因素中，土壤是相當重要的因素之一(Horisue 1983; Matsue 1993; Chen *et al.* 1988)。Chamura等(1972)指出日本沖積土及洪積土等土壤生產的稻米，食味優於火山灰土壤及泥炭土。Hou *et al.* (1988)比較臺灣四種質地土壤生產的稻米，以黏壤土生產之稻米食味較佳。Chen *et al.* (1994a)調查本省中部108處稻田，指出黏板岩新沖積土生產的稻米米飯食味較優。此等研究顯示良質米栽培生產過程，土壤確是一重要影響因素，其中又牽涉土壤母質、土壤肥力、理化性質等特性。Chen *et al.* (1994a; 1994b)曾探討土壤母質及肥力對米質之影響，本文將繼續探討關於土壤各種物理化學性質對米質的影響，據以建立良質米生產之土壤管理模式，以為改善米質栽培管理之參考。

材料與方法

本試驗自1989年二期作至1991年二期作共五期作，於本省中部地區90處稻田，進行良質米栽培、土壤化學性質及物理性質調查。水稻採用良質米品種台農70號及台中189號，栽培管理及施肥依一般慣行法，水稻生育後期進行土壤採樣，每處稻田逢機採二十點以上，經風乾混合後，進行各項土壤理化性質分析。土壤pH：水、土比為1:1，以玻璃電極測定(Van Lierop 1990)。土壤全氮：土壤樣品以濃硫酸分解，加入10N NaOH蒸餾，以2%硼酸收集氨氣，最後以0.01N硫酸滴定(Bremner 1965)。有效性磷：取2.0g土壤樣品，以0.5N鹽酸及氟化銨(NH_4F)混合液萃取，與鉬酸銨溶液反應，再以還原劑氯化亞錫還原，最後以光電比色計波長660nm測定(Olson and Sommers 1982)。交換性鉀、鈣、鎂：土壤樣品以1N醋酸銨(pH 7.0)振盪30分鐘後過濾，鉀以火燄光度計測定，鈣、鎂以原子吸光儀測定(Page et al. 1982)。游離鐵及易還原錳：土壤樣品以0.1N HCl振盪40分鐘萃取，再以原子吸光儀測定(Viets and Lindsay 1983)。

土壤穿刺阻力：在分蘗盛期土壤曬田後，重行灌溉以前，以土壤穿刺阻力計(Hogentogler, Model P. O. Drawer 2219)測量土壤剖面30公分深度內每

3公分之穿刺阻力變化。水田滲漏速率：在水稻分蘗盛期前，土壤湛水情況下，以自製黃金電極，測定一定時間內水分往下滲漏之速率。土壤氧化還原電位：以自製白金電極插入土中，深度約 8 公分，待平衡24小時後，測電動勢(emf)，並換算土壤氧化還原電位，參考電極爲4M氯化銀電極。並根據連續一週測值估算迴歸係數，換算氧化還原電位下降速率(mv/day)。灰斑層深度：以土鑽採取土壤剖面140公分深度內每20公分之土樣，置於剖面盒內觀察並檢算灰斑層出現深度。水稻根活性：在水稻齊穗期，採稻根以TTC法(Sagami and Fujimaki 1960)測定根活性。

水稻成熟後每處採樣三點，每點收穫100株，經乾燥調製至水分含量14.5%，進行米質食味及均衡度(Balance)分析，此部分由台中區農業改良場米質研究室協助，由十位品評員組成的評審團加以品評分析，品評項目包括外觀、香味、口味、黏性、硬性，以及前述五項之綜合評估爲總評(Hsu and Song 1988)。在各項食味品評項目中，品評員根據上述的米飯各品評項目，作爲判斷米飯優劣的依據(Carmen 1969)，較對照佳者評分大於零，與對照不分上下評分等於零，若比對照差者評分小於零。此外並以質地分析儀(Texturometer, Zenken)分析米飯物理性質之均衡度(-H/H)，以瞭解品評員官能品評與機械分析數值間之關係。兩者皆以彰化田中地區當期生產的台中189號良質米爲對照。

米飯品質的判斷較難以量化方式客觀比較，因此將試驗所得資料，依米飯食味總評與對照比較後區分爲優（評分較對照佳）、中（評分與對照相同）、劣（評分低於對照）三組，並以優劣兩者進行對比，以檢定其間之差異顯著性（Chen et al. 1994a）。米飯均衡度的高低則依據Okabe (1979)的理論進行分類，米飯均衡度區分爲A-E級，由於台灣目前的水稻品種米飯均衡度甚難達到0.15以上，在本試驗調查的米飯均衡度亦未出現A級者，因此以B及C級視爲較優，E級爲劣，最後同樣以優劣兩者進行對比。

結果與討論

本試驗調查土壤pH、游離鐵、易還原錳、氧化還原電位及其下降速率等有關土壤化學性質與米飯食味及均衡度之關係。土壤pH爲重要之化學性質，其左右營養元素有效性。游離鐵及易還原錳除扮演植物營養的角色外，同時也扮演影響水田氧化還原變化的主要角色，間接影響水稻根活性。

由米飯食味與土壤特性之相關分析，顯示土壤氧化還原電位下降速率與食味總評達極顯著正相關(r=0.46)外，其他土壤pH、游離鐵、易還原錳及氧化還原電位起始值均與食味呈顯著或極顯著負相關（表一）。另外由米飯均衡度與土壤特性之相關分析中亦有類似相關性之趨勢，土壤pH、易還原錳、氧化還原電位與米飯均衡度呈顯著負相關，唯氧化還原電位下降速率與米飯均衡度未達顯著正相

Table 1. Correlation coefficients of overall sensory evaluation and balance for rice quality and soil properties.

	pH	Fe	Mn	Eh	Ehs	Per	RA	Pen	DG
Overall sensory	-0.28*	-0.31**	-0.37**	-0.41**	0.46**	-0.02	0.17	0.21	-0.05
Balance	-0.35**	-0.14	-0.31**	-0.44**	0.22	0.01	0.08	0.18	0.13

Eh: Redox potential; Ehs: Slope of redox potential declined; Per: Percolation rate; RA: Root activity; Pen: Penetration resistance; DG: Depth gley layer.

*, **: Significantly correlated at α=0.05 and 0.01, respectively.

關，土壤游離鐵與米飯均衡度未達顯著負相關（表一）。

區分米飯食味總評爲優及劣兩組並加以對比，顯示pH及易還原錳含量較低之土壤，所生產之稻米食味較佳（表二），生產食味較優稻米之土壤pH平均爲5.0，易還原錳含量爲68ppm。生產食味較差稻米之土壤pH則平均達5.8，易還原錳含量更高達297ppm，生產優良及低劣米質之土壤兩者皆達極顯著差異，顯示pH較低的土壤似乎對米飯食味有較正面的作用，pH較低的土壤通常肥力較差，由於土壤pH主要受土壤中鈣含量的影響，排水良好沖積土的稻田，土壤鈣淋洗較快速，因而使pH降低，此處低pH土壤生產稻米品質較優，可能在反映土壤通氣排水之影響。土壤游離鐵的含量則對米飯食味無明顯影響。氧化還原電位下降速率較慢(-4.11mv/day)之土壤，稻米食味亦有較優之趨勢。相形之下，氧化還原電位下降速率平均較快(-44.7mv/day)之土壤，其米飯食味較差，此點與前述pH較低，排水通氣較佳的土壤，生產稻米品質較佳推論一致。

同樣的pH值較低、易還原錳含量較低之土壤（分別爲4.6及30ppm）生產之稻米，米飯均衡度較佳（表三）；生產稻米均衡度較差之土壤，其pH及易還原錳均較高，分別爲6.4及298ppm，同樣的沖積土，pH及易還原錳低的土壤，屬於通氣排水較佳的土壤，此一結果與前述推論相符。氧化還原電位下降速率較慢，平均爲6.23 mv/day之土壤，生產之稻米均衡度有較佳之趨勢；反之，氧化

Table 2. Overall sensory evaluation for rice eating quality as affected by soil chemical preperties (2nd crop 1989~1st crop 1992).

Overall sensory evaluation	pH**	Fe	Mn**	Initial redox potential	Initial** potential declined
		ppm	ppm	mv	mv/day
Good#	5.0±0.2	1537±114	68±17	-214±19	-4.11±1.4
Fair	5.7±0.5	1587±145	91±34	-227±30	-6.39±0.8
Poor	5.8±0.2	1584±94	297±46	-178±14	-44.74±15.4

: Rating evaluated by sense in comparison with rice cultivar Taichung 189, which cultivated in Tien-Chung, Chang-Hwa county, as the control, "good"=rating of eating quality higher then the control, "fair"=rating equal to the control, and "poor"=rating lower than the control, respectively.

** : Significantly different between ratings of "good" and "poor" at α=0.01 by t-test, respectively.

Table 3. Balance (-H/H) of rice quality as affected by soil chemical preperties (2nd crop 1989~1st crop 1992).

Balance	pH**	Fe	Mn**	Initial** redox potential	Redox** potential declined
		ppm	ppm	mv	mv/day
B & C#	4.6±0.1	1619±95	30±6	-249±23	-6.23±0.59
D	5.7±0.2	1486±81	241±41	-197±12	-21.10±11.74
E	6.4±0.4	1977±256	298±30	-72±32	-100.38±36.63

: Classified by the range of -H/H, i.e. A:0.15-0.20, B:0.13-0.15, C:0.10-0.13, D:0.05-0.10 and E:<0.05, respectively (Okabe, 1979).

**: Means between ranks (-H/H) of B & C and E are significantly difference at α=0.01 by t-test.

還原電位下降速率較快，平均爲100 mv/day之土壤，生產之稻米均衡度較差。Chen (1992)指出改善還原電位有助於改善水稻根活性，可能因而改善米質。水稻栽培過程中，根系活性吸收影響生育表現，氧化還原電位下降速率較慢之土壤，顯示其排水通氣較佳，可能因而改善米質。

土壤穿刺阻力影響作物根系的伸展，也反映部分的土壤質地與構造。本試驗結果顯示生產稻米之米飯食味較佳的土壤，其曬田後穿刺阻力有較大的趨勢，平均達19.8Kg/cm^2，米飯食味較差之土壤，穿刺阻力平均僅有15.9Kg/cm^2（表四）。由於土壤穿刺阻力之測定在曬田後進行，經過最高分蘗期曬田程度較高者，土壤穿刺阻力往往因而提昇(Chen 1991; Chen *et al.* 1991)，是以曬田後測得土壤穿刺阻力較大者，可能代表分蘗盛期曬田程度高，另一方面也可能表示土壤黏粒比例相對較高，經曬田後導致穿刺阻力變大。Chen (1992)亦指出，曬田程度較高，土壤氧化還原電位較高者，由於銨態氮的損失、硝化以及後續脫氮作用的盛行，使得水稻氮素吸收減少，也減少米粒蛋白質的累積，可能因而改善米質。土壤剖面灰斑層深度較深者，土壤排水通氣良好，可望生產食味較佳之稻米，但未達顯著差異。其餘水田滲漏速率及稻根活性則均無明顯之差異。在米飯均衡度方面，亦有相似之結果，亦即生產稻米均衡度在D及E等級以下者，曬田後土壤穿刺阻力較低，分別爲平均17.4及13.9Kg/cm^2，反之，生產稻米均衡度較好之B及C級（台灣目前的水稻品種米飯均衡度甚難達到0.15以上，在本試驗調查的米飯均衡度亦沒有出現A級者，表三），曬田後土壤穿刺阻力較高，平均爲

Table 4. Overall sensory evaluation for rice eating quality as affected by soil physical preperties (2nd crop 1989~1st crop 1992).

Overall sensory evaluation	Percolation rate	Root activity	Penetration** resistance	Depth to gley layer
	mm/day	A/g dry wt. root	kg/cm^2	cm
Good#	6.73±2.57	4.13±0.48	19.8±1.19	73.08±9.89
Fair	3.82±1.08	4.97±0.56	20.8±2.48	61.00±13.74
Poor	8.87±3.52	4.92±0.49	15.9±0.66	61.37±6.0

#: Rating evaluated by sense in comparison with rice cultivar Taichung 189, which cultivated in Tien-Chung, Chang-Hwa county, as the control, "good"=rating of eating quality higher then the control, "fair"=rating equal to the control, and "poor"=rating lower than the control, respectively.

**: Significantly different between ratings of "good" and "poor" at α=0.01 by t-test, respectively.

Table 5. Balance (-H/H) of rice quality as affected by soil physical preperties (2nd crop 1989~1st crop 1992).

Balance	Percolation rate	Root activity	Penetration** resistance	Depth to gley layer
	mm/day	A/g dry wt. root	kg/cm^2	cm
B & C#	5.23±1.8	4.05±0.7	19.4±1.77	83.33±12.74
D	8.61±3.2	5.21±0.4	17.4±0.72	56.19±5.25
E	6.88±2.2	2.65±0.4	13.9±3.98	95.00±17.59

#: Classified by the range of -H/H, i.e. A:0.15-0.20, B:0.13-0.15, C:0.10-0.13, D:0.05-0.10 and E:<0.05, respectively (Okabe, 1979).

**: Means between ranks (-H/H) of B & C and E are significantly difference at α=0.01 by t-test.

19.4Kg/cm^2（表五）。

土壤營養元素間的比例影響元素間之拮抗作用及作物吸收的選擇性，試驗結果顯示，在Ca/Mg比值較高（平均8.4），N/K比值較低（平均=26.7），Mg/K比值較低（平均=7.6）之土壤，生產稻米食味較佳（表六）；反之，Ca/Mg比值較低（平均4.4）。N/K比值較高（平均35.6），Mg/K比值較高（平均14.2）之土壤，生產稻米食味較差。亦即土壤Ca/Mg比值較高及N/K、Mg/K比值較低者，米飯食味總評有較佳之趨勢。較低之N/P比值亦有生產食味較佳稻米之趨勢，但未達顯著差異。Horino及Okamoto (1992)的試驗結果顯示糙米及白米之Mg/K比值與食味品評的結果呈正相關，此與上述土壤結論之間的差異性有待進一步探討。

在米飯均衡度方面，土壤Ca/Mg比值較高（平均9.6），Ca/k、Mg/K比值較低（平均分別爲37.0、4.8）者，生產之稻米均衡度有較佳之趨勢（表七），當土壤Ca/Mg比值較低，僅4.3，Ca/K

Table 6. Overall sensory evaluation for rice eating quality as affected by ratio of soil elements (2nd crop 1989~1st crop 1992).

Overall sensory evaluation	N/P	N/K*	Ca/Mg**	Ca/K	Mg/K**
Good#	97.2±24.9	26.7±2.4	8.4±1.3	51.1±8.7	7.6±1.1
Fair	83.4±23.1	31.5±5.7	4.4±0.8	51.6±17.5	10.0±1.8
Poor	126.9±28.8	35.6±2.9	4.4±0.4	59.2±6.3	14.2±1.2

#: Rating evaluated by sense in comparison with rice cultivar Taichung 189, which cultivated in Tien-Chung, Chang-Hwa county, as the control, "good"=rating of eating quality higher then the control, "fair"=rating equal to the control, and "poor"=rating lower than the control, respectively.

*,** : Significantly different between ratings of "good" and "poor" at α=0.05 and α=0.01 by t-test, respectively.

Table 7. Balance (-H/H) of rice quality as affected by ratio of soil elements (2nd crop 1989~1st crop 1992).

Balance	N/P	N/K	Ca/Mg**	Ca/K**	Mg/K**
B & C#	94.2±20.9	24.3±1.6	9.6±1.8	37.0±7.2	4.8±0.6
D	124.9±26.3	36.1±2.7	4.8±0.4	59.4±6.5	12.7±1.6
E	69.9±12.5	24.0±3.0	4.3±0.5	65.9±7.3	16.2±2.1

: Classified by the range of -H/H, i.e. A:0.15-0.20, B:0.13-0.15, C:0.10-0.13, D:0.05-0.10 and E:<0.05, respectively (Okabe, 1979).

**: Means between ranks (-H/H) of B & C and E are significantly difference at α=0.01 by t-test.

及Mg/K比值較高，分別爲65.9及16.2之土壤，則生產稻米均衡度有較差之趨勢。土壤Fe/P比較高(102.0)者，較之Fe/P比值較低者(79.0)，亦有生產均衡度較佳稻米之趨勢，但未達顯著差異。

就上述結果，顯示土壤中一價陽離子鉀含量較高時，容易獲得米質的提升，此點是否由於土壤鉀含量較高，可能抑制水稻氮素的過量吸收，抑或牽涉到穀粒澱粉累積之機制，由於各離子互相間的關係相當複雜，仍有待進一步研究闡明。

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